EXPERIMENTAL STUDY ON EXPANDED FLYASH CLAY AGGREGATE (EFCA) AS AN ALTERNATIVE COARSE AGGREGATE IN CONCRETE

A SYNOPSIS

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1. INTRODUCTION

Cement, fine aggregates, coarse aggregates and water are the primary constituents of concrete. As infrastructure expands, the demand and use of concrete are increasing continuously, which raises the demand for its constituent ingredients. Aggregates used in concrete are world's most mined substances. Increasing building and urbanisation have pushed aggregate demand to a new high level. This necessitates an increase in the number of mining quarries on our planet. This situation is extremely hazardous to the environment. It also hastened the dwindling of our natural resources. By means of reducing environmental damage and the depletion of natural resources, scientists are investigating possible substitutes for currently used substances.

Many by-products around the globe have taken place as some of the components in concrete. Some of them are fly ash, silica fume, rice husk ash, and metakaolin. Thermal power plants produce fly ash as a derived product of the combustion process. Fly ash occupies a huge space, and its disposal has become a significant concern in the current era. Fly ash is now employed as an ingredient in concrete, bricks, and cement manufacturing, among other things. In this current study, fly ash and red clay soil are employed to make artificial coarse aggregates. It was procured by the Tuticorin thermal power plant, and red clay soil was collected in the Kanyakumari district of Tamil Nadu.

An effort is being made to create a sustainable coarse aggregate for concrete using locally accessible soil and fly ash waste in this endeavour. Class F fly ash from the Tuticorin thermal power plant and red clay soil from the Kanyakumari district were used in this project. For aggregate preparation, six distinct mixes of fly ash and red clay are used. The percentage of fly ash and red clay (30:70) was determined as the optimal combination based on the physical and mechanical characteristics of the aggregates. The M20 grade of concrete was adopted and designed in accordance with the requirements of IS 10262: 2009. Locally available river sand and 53 grade of Portland Pozzolana Cement (PPC) cement were employed. The physical and chemical characteristics of all materials were analysed.

Further research was carried out by incorporating EFCA for partial and total replacement. Normal concrete and EFCA concrete fresh and hardened performance were evaluated and compared. The properties of conventional coarse aggregate and

EFCA concrete were compared and confirmed against different codes and literature. The EFCA concrete was subjected to durability trials like water absorption, Rapid chloride ion penetration, Acid resistance, and sulphate attack and was compared to control concrete. A high temperature was applied to concrete samples, including conventional natural aggregate and EFCA coarse aggregate. The fired samples were then tested for mass loss, residual strength, and water absorption. Microstructural analysis of fired specimens was performed, and test results were compared to normal aggregate concrete.

2. LITERATURE REVIEW

Sebastin et al. [1] investigated the concrete characteristics of red soil and river sand in various quantities. Red soil has a high porosity and low permeability, allowing it to absorb a significant amount of water compared to regular river sand. The produced concrete exhibited greater strength when the proper ingredients were combined.

Nallaiahgari and Vema [2] investigated the impact of concrete mechanical characteristics when fly ash aggregates were utilised as coarse aggregates. The characteristics of conventional concrete and fly ash aggregate concrete were examined. Fly ash aggregate concrete worked better than normal concrete. The sphere-shaped form of the fly ash aggregates subsidized the improved performance. As a result, the superplasticiser dose can be decreased in the case of fly ash aggregate concrete. When fly ash was used as coarse aggregates, the density of concrete was condensed by 15% when related to ordinary concrete. The density was reduced because of the low weight of fly ash aggregates.

The characteristics of fly ash aggregates appropriate for usage as coarse aggregates were reviewed by Nadesan and Dinakar [3]. Following their review, the following findings were made. Notably, the fineness of the fly ash greatly impacts the aggregate's physical characteristics. The fly ash aggregates were spherical in form and had a specific gravity between 1.33 and 2.35. Fly ash aggregates have lower permeability and chloride penetration than conventional aggregates. The fly ash aggregate concrete outperformed traditional concrete in terms of corrosion resistance.

Atluri et al. [4] investigated the strength characteristics of artificial lightweight aggregate. Five variant combinations were employed in the aggregate production. It was determined that as fly ash replaced natural aggregate, characteristics such as density, compressive strength, flexural strength and young's modulus declined progressively. When the experimental results of flexural strength are compared to the calculated results derived using the IS 5816:1999 [5] formula, the experimental results are shown to be on the higher side.

Viveka and Renuka [6] performed experiments on concrete by substituting fly ash aggregates for coarse and fine aggregates. The trials used concrete with 100 percent fly ash fine aggregate and varied the substitution percentage of coarse aggregate by fly ash from 0 to 100 % with a 10 percent increment in each subsequent trial. Concrete was employed to make the fly ash aggregates by mixing cement and fly ash 25:75 at a water-to-cement ratio of 0.3. In a concrete drum mixer, the ingredients were blended until pellets were created, and then the pellets were allowed to dry for seven days. For seven days, the dry pellets were soaked in water. With a water-cement ratio of 0.451, the mix design for M25 concrete was 1:1.36:2.41. In comparison to the other mixes, using fly ash aggregates to substitute 30% of the coarse aggregates resulted in higher compressive strength. Concrete had a target strength of 25 MPa up to 60 percent replacement, but its strength decreased afterwards.

Ravisankar et al. [7] utilised artificial fly ash aggregates in concrete, and their impact strength was explored. Flexural strength was high in fly ash aggregate concrete with a cement fly ash percentage of 30:70.

Acar et al. [8] evaluated the sinterability of two class F fly ashes types. They experimented with the sintering temperature and time. To assess sintering efficiency, ceramic properties such as bulk, water permeability, shrinkage, and elastic modulus were employed. In addition, XRD and SEM analyses were performed to detect phase shifts and microstructural changes generated by the sintering process. Fly ash is preferred because of its better microcrystalline structure, stronger density and strength, lower porosity, water permeability and drying shrinkage values.

According to Job Thomas and Harilal [9], the polarisation method was used to create the aggregate, which was then bound with standard Portland cement and various

fly ash and quarry dust proportions. It is shown that three different kinds of artificial aggregate have various strengths. Every 28 days, concrete is tested for porosity compaction factor and compressive strength at w/c ratios of 0.35, 0.45, 0.55, and 0.65. Because the above-mentioned aggregate is a feasible substitute for natural aggregate, it can be expected to have less of an impact on the concrete industry's environment further forward.

Priyadharshini et al. [10] made artificial aggregates from fly ash and cement by partially substituting them. The natural resources of artificial aggregates are extracted through the pelltization technique from fresh aggregates that are dry at room temperature. The curing was finished using a cold bonded method, which will be employed as additional aggregate material in concrete. However, it satisfies the minimum standards for lightweight structural concrete while having a compressive strength 48% lower than conventional concrete. Rounder fly ash aggregates were simpler to work with than angular crushed aggregates. The density of fly ash concrete was shown to be 15% lesser than that of regular concrete.

Kayali [11] investigated the characteristics of using various coarse aggregates. The coarse aggregates utilised in the investigation were granite, dacite, commercially supplied pelletized fly ash aggregates (SP), and artificially produced fly ash aggregates created from fly ash (FAA). Using the coarse aggregates listed above, four distinct concrete mixes were created. The concrete using commercial fly ash pellets was labelled SP concrete, whereas the concrete containing artificial fly ash aggregates was labelled FAA concrete. The performance of all four concrete mixtures was tested using a slump cone. The slump of SP and FAA concrete was much greater than the slump of granite and dacite aggregate-containing concrete. The usage of fly ash aggregates decreased the density of the concrete. As a result, SP and FAA concrete were less dense as related to normal concrete.

Experimental work on the production of fly ash pellets by Harikrishnan and Ramamurthy [12]. They indicated that the effectiveness of pellet production is determined by the speed of the pelletizer disc's revolution, the moisture content, the pelletizer disc's angle, and the pelletization length.

3. RESEARCH OBJECTIVE

- To develop a suitable soil-fly ash mix to produce an alternate coarse aggregate and identify the optimal combination of Expanded Fly Ash-Clay Artificial Coarse Aggregates (EFCA).
- To determine the mechanical properties of developed EFCA to assess the suitability of using as coarse aggregate in the designed concrete mix.
- To compare the workability, strength and durability of developed EFCA with conventional concrete.
- To investigate the behaviour of developed concrete at normal and elevated temperatures to assess the surface changes, weight loss and chemical changes.

4. EXPERIMENT AND ANALYSIS

4.1 Preparation of Expanded Fly Ash Clay Aggregates

Expanded fly ash clay aggregates are made from ingredients, such as fly ash, red clay soil and water. Fly ash is added to the soil mix in various proportions to produce six batches of samples, and aggregates are produced separately for each mix. Six various mixtures of fly ash and red clay soil were explored, including 0:100, 10:90, 20:80, 30:70, 40:60, and 50:50. Soil and fly ash are moistened with potable water and then moulded into a plastic-like substance. Fresh granular aggregates <10mm were arranged using a basic hand press; the granular shape was derived by hand shaping. Fresh aggregate is subjected to a three-stage treatment process to increase strength. It is sun-dried for one day after the new aggregate has been kept at room temperature for 24 hours. For the next 24 hours, it is kept in a drying oven at 110^{o}C. The final phase involves burning it at 950 degrees Celsius in an electric furnace. The temperature progressively increases by 100^{o}C increments until it reaches roughly 950°C. The burnt aggregates gradually cooled to normal temperature. Segregation and gradation of expanded fly ash clay aggregates are done.

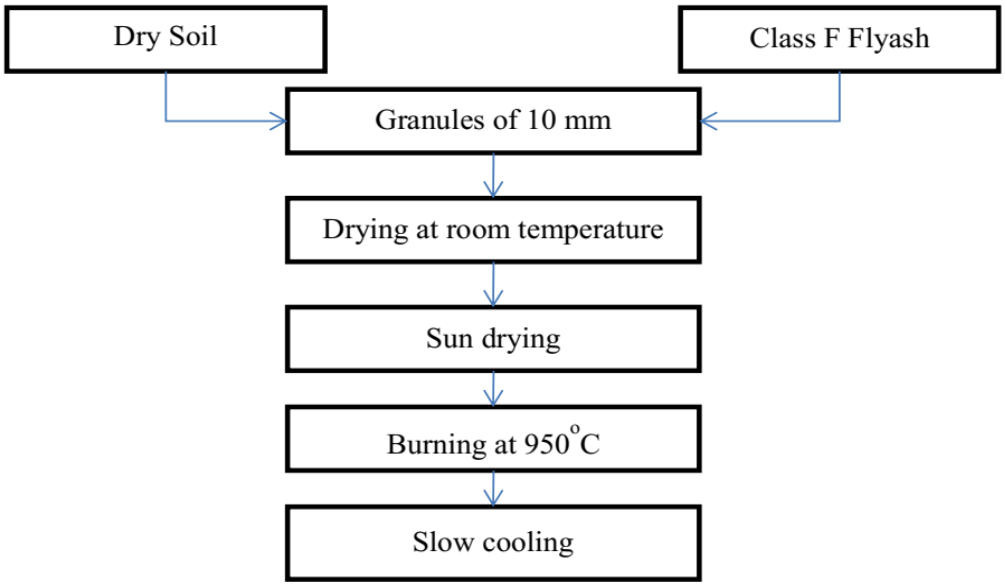

Figure 1 Flowchart of EFCA production process

4.2 Physical Behaviour of Expanded Fly Ash Clay Aggregate (EFCA)

The physical behaviour of Expanded fly ash clay aggregate (EFCA) and natural coarse aggregate (NA). The Specific gravity, bulk density and water absorption were observed in all mix combinations. The results of the experiments are given in Table 1. Further, the gradation of coarse aggregates was studied.

Table 1 Physical Characteristics of coarse aggregates

Sl. No	Mix ID	Specific gravity	Bulk density kg/m^3	Water absorption %	Fineness modulus
1	EFCA1	1.57	1100	11.9	6.71
2	EFCA2	1.56	1080	14.8	6.79
3	EFCA3	1.55	1060	16.3	6.84
4	EFCA4	1.54	1040	17.8	6.97
5	EFCA5	1.54	987	18.8	6.76
6	EFCA6	1.53	970	21.3	6.82
7	NCA	2.82	1490	0.66	7.12

4.3 Mechanical Behaviour of Expanded Fly Ash Clay Aggregate (EFCA)

The mechanical behaviour of EFCA aggregate and NA were compared for aggregate impact value, Aggregate crushing value and aggregate abrasion resistance. The table showing the mechanical properties of various mix proportions of EFCA and NA as per IS 2386: (part I) 1963 [13] is given in Table 2.

Table 2 Mechanical properties of EFCA

Sl.No	Mix Identification	Impact Value	Crushing Value	Abrasion value
1	EFCA1	29.8	1.48	14.88
2	EFCA2	28.7	1.47	16.25
3	EFCA3	28.3	1.51	16.74
4	EFCA4	27.8	1.53	13.59
5	EFCA5	30.6	1.34	12.15
6	EFCA6	45.2	1.13	12.18
7	NCA	30.1	2.68	20.18

4.4 Preparation of EFCA concrete

In order to get the properties of fresh and hardened concrete, the mix proportioning technique combines different concrete materials based on their qualities to meet the needs of safe and functional constructions. The workability in a fresh state, Compressive strength, density, water permeability, and the structure's service life depends upon the concrete's quality. Control Concrete Mix Proportioning having a 28-day compressive strength of 25 MPa was developed. The mix design was carried out based on IS 10262-2009 [14]. Table 3 shows the mixed proportioning of various ingredients.

Table 3 Mix proportioning

Sl. No.	Mix ID	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)		Water (litres)
				NCA	EFCA	
1.	NCAC	386	793.6	882.6	--	182
2.	CFAC	432	793.6	--	508.8	203

Different mixes were prepared in different combinations of EFAC and NA ratios. Table 4 shows the proportions. The batching, mixing, and casting processes were executed with great care and precision. An accuracy of 0.5 grams was used to weigh the coarse and fine aggregates before the final product was measured. On a waterproof platform, the concrete mixture was manually mixed. The correct proportions of fine aggregates are added and thoroughly mixed. The batching, mixing, and casting processes were executed with great care and precision. After weighing both the coarse and fine aggregates, the final result was measured with an accuracy of 0.5 grams. On a waterproof platform, the concrete mixture was manually mixed.

Table 4 Partial Replacement for EFCA Aggregate in Concrete Mix

Sl.NO	Mix ID	NCA %	EFCA %
1	CC	100	0
2	FCAC1	75	25
3	FCAC2	50	50
4	FCAC3	25	75
5	FCAC4	0	100

Table 5 shows the details of samples cast for various tests as per IS456:2000 [15]. Rapid chloride penetration test as per ASTM C 642-97 [16], Non destructive testing as per IS 13311 (Part 2): 1992 [17],

Table 5 Details of Test Conducted and Specimen Details

Sl. No.	Name of the test	Properties evaluated	Size of the specimen	Number of specimens cast
1.	Compression test	Compressive strength	150 mm cubes	75
		Stress-strain Relationship	Cylinder (150 mm dia. x 300 mm high)	30
2.	Split tensile test	Split tensile strength	Cylinder (150 mm dia. x 300 mm high)	45
3.	Flexural Test	Flexural strength	Beam (100 mm x 100 mm x 500 mm)	45
4.	Rapid chloride penetration test (RCPT)	Chloride penetration	Cylinder (100 mm dia. x 50 mm high)	30

5.	Water absorption test	Absorption of water	150 mm cubes	15
6	Sulphate attack test	Resistance in sulphate attack	150 mm cubes	45
7	Acid Resistance Test	Resistance in acidic environment	150 mm cubes	15
8	Thermal analysis	Impact of thermal studies	100mm Cubes	90

4.5 Mechanical and durability properties of EFCA concrete

The workability of fresh concrete is studied using slump value, compaction factor and flow values. Table 6 shows the results of workability tests on various mix proportions.

Table 6 Fresh concrete characteristics of various concrete mixes

S.No	Mix ID	Slump (mm)	Compaction factor	Flow test %
1	CC	85	0.92	102
2	FCAC1	88	0.89	112
3	FCAC2	90	0.91	118
4	FCAC3	92	0.92	124
5	FCAC4	94	0.94	130

The compressive strength, flexural strength and split tensile strength of hardened concrete are tested and tabulated in Table 7 as per ACI 318-14 [18] and IS 5816:1999 [19] and IS 13311 (part 2) : 1992 [20].

Table 7 Mechanical characteristics of EFCA concrete and normal concrete

Sl. No.	Mix ID	Compressive strength at 28 days N/mm^2	Split tensile strength at 28 days N/mm^2	Flexural strength at 28 days N/mm^2
1.	CC	26.84	3.38	5.43
2.	FCAC1	20.31	3.04	4.14

3.	FCAC2	23.48	2.83	3.85
4.	FCAC3	22.63	2.39	3.53
5.	FCAC4	21.45	1.85	3.67

Non-destructive tests were conducted on hardened concrete, ultrasonic pulse velocity test and rebound hammer test were conducted, and the results are tabulated in Tables 8 and 9.

Table 8 Ultrasonic pulse velocity test results

Sl. No.	**Mix ID**	**Pulse velocity at 28 days (Km/sec)**	**As per IS 13311 (Part I): 1992**
1.	CC	4.27	Good
2.	FCAC1	3.98	Good
3.	FCAC2	4.31	Good
4.	FCAC3	4.35	Good
5.	FCAC4	4.67	Excellent

Table 9 Rebound hammers test result for EFCA concrete specimens

Sl. No.	**Mix ID**	**Compressive strength at 28 days as per IS 13311 (Part II):1992 N/mm^2 (DT)**	**Compressive strength for N/mm^2 (RHT)**	**Difference between RHT and Direct Test results (%)**
1.	CC	26.84	23.15	15.94
2.	FCAC1	20.31	17.42	16.60
3.	FCAC2	23.48	21.29	10.28
4.	FCAC3	22.63	20.33	11.31
5.	FCAC4	21.45	19.95	7.51

The durability of hardened concrete is tested by a rapid chloride ion penetration test, and an acid resistance test was conducted with sodium sulphate, magnesium

sulphate and sulfuric acid. The results were Tabulated in 10, 11, 12, 13. The water absorption was Tabulated in 14.

Table 10 Rapid Chloride Ion Penetration test result for CC AND EFCA concrete specimens

S.No	MIX ID	Charge (Q) in Coulomb (C)		Chloride Permeability As Per ASTM C-1202
		28 DAYS	90 DAYS	
1	CC	1155.19	1068.46	Low
2	FCAC1	1968.23	1837.21	Low
3	FCAC2	2958.41	2665.79	Moderate
4	FCAC3	2754.85	2523.65	Moderate
5	FCAC4	2580.02	2321.42	Moderate

Table 11 Weight of specimens and compressive strength after exposure to Na2SO4 solution for various periods

MIX ID	Weight in Kg				Compressive Strength, N/mm2			
	0 d	28 d	56 d	90 d	0 d	28 d	56 d	90 d
CC	7.57	7.50	7.49	7.48	25.35	26.78	25.51	24.97
FCAC1	7.48	7.40	7.37	7.32	21.21	20.20	19.91	19.65
FCAC2	7.17	7.12	7.10	7.04	22.47	23.10	22.89	22.80
FCAC3	6.85	6.80	6.74	6.69	23.86	22.34	22.11	21.91
FCAC4	6.31	6.27	6.21	6.13	22.95	21.23	21.07	20.94

Table 12 Weight of specimens after exposure to $MgSO_4$ solution for various periods

MIX ID	Weight of specimen in KG				Compressive Strength, N/mm^2			
	0 d	28 d	56 d	90 d	0 d	28 d	56 d	90 d
CC	7.59	7.50	7.47	7.22	26.84	25.11	24.65	24.23
FCAC1	7.49	7.40	7.28	7.26	20.31	20.04	19.45	18.14
FCAC2	7.20	7.08	7.01	6.98	22.63	22.34	21.94	21.78
FCAC3	6.83	6.73	6.65	6.61	23.48	23.19	22.86	22.19
FCAC4	6.30	6.20	6.08	6.07	21.45	21.17	20.89	20.14

Table 13 Test results of cube specimens for acid resistance

Sl. No.	Mix ID	Weight of specimen (kg)		Compressive strength (N/mm^2)	
		Before acid curing	After acid curing	Normal Water curing	Under Acid curing
1.	CC	7.61	7.46	26.12	24.02
2.	FCAC1	7.50	7.32	20.31	19.12
3.	FCAC2	7.18	7.03	23.48	20.55
4.	FCAC3	6.83	6.72	22.63	21.52
5.	FCAC4	6.33	6.18	21.45	20.35

Table 14 Water absorption of cube specimens

Sl. No.	Mix ID	Dry weight (kg)	Saturated weight (kg)	Water absorption in (%)
1	CC	7.61	7.89	3.78
2	FCAC1	7.49	7.91	5.63
3	FCAC2	7.20	7.73	7.45
4	FCAC3	6.84	7.40	8.21
5	FCAC4	6.35	6.92	8.98

4.5 Thermal behavior of EFCA concrete

In this study, an electric furnace with dimensions of 300 mm x 300 mm x 609 mm is used. With a K-type thermocouple, the furnace can reach the highest temperature of 1200°C. The furnace was accomplished by sustaining a constant temperature with a precision of ±1 °C. A temperature of 200°C, 400°C, 600°C, and 800°C is the maximum temperature reached for each sample, which is then allowable to cool down inside the furnace to attain room temperature before being tested. The effects of fire on concrete's mineral properties were examined. Before and after exposure to fire, each specimen was weighed to an accuracy of one gram. The loss in mass and loss in compressive strength is tabulated in Tables 15 and 16.

Table 15 Loss in mass of Specimens after exposure to fire

S.NO	Temperature (°C)	Loss in Mass (%)	
		EFCA Specimen	NCA Specimen
1	200	2.63	7.15
2	400	6.79	10.6
3	600	7.85	11.03
4	800	8.18	12.93

Table 16 Residual compressive strength of fired specimens

MIX ID	Compressive Strength value (N/mm^2)				
	Before applying heat	200°C	400°C	600°C	800°C
NAC Specimens	26.66	20.25	19.55	18.43	13.32
EFCA Specimens	21.45	22.07	20.84	18.63	17.17

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4.6 Conclusion

The bulk density of EFCA was < 1100 kg/m ^{3}. As a result, these aggregates are lightweight aggregates according to IS: 9142 – 1979(21). Because of its highly porous nature, EFCA aggregates are unsuitable for concrete exposed to freezing and thawing. According to IS 383: 2016, up to 30% of impact value can be used for all concrete works. Because EFCA has a crushing value of less than 2%, it can be used in a concrete mix. When compared to natural aggregate, the abrasion value of EFCA is lowered by 25% to 50%. Thus, EFCA is more durable against abrasion than the normal aggregate. Artificial aggregates were created using fly ash and red clay, exhibiting all the desirable characteristics of coarse aggregates. When all six EFCA proportions used in this work are considered, EFCA 4 has better physical and mechanical properties than the other mixes used. As a result, EFCA 4 was chosen as the best EFCA preparation mix.

The fresh concrete properties of all normal concrete and Expanded fly ash clay aggregate concrete mixtures were assessed by maintaining a slump of less than 100mm**.** The oven-dry densities of all EFCA mixtures evaluated were less than 2000 kg/m^3.EFCA concrete is classified as lightweight concrete because conventional concrete has a density of between 2200 and 2600 kg/m^3. The rise in the water absorption capacity of EFCA concrete results in significantly lower oven-dry densities than conventional concrete.

After 28 days of curing, the compressive strength of the EFCA samples ranged between 20.31 and 21.45 N/mm^2. It is significantly lesser than conventional concrete, but after 90 days, the strength has gradually increased owing to the pozzolanic properties of cement. The splitting tensile strength of EFCA concrete determined experimentally was greater than the value determined according to IS 456: 2000. While normal concrete also achieved a high splitting tensile strength experimentally, the increase was slightly greater in the FCAC1 mix than in the other mixes. The flexural strengths of conventional concrete and EFCA concrete determined experimentally are greater than those obtained in accordance with IS 456: 2000(). EFCA concrete is better appropriate for standard-grade concrete. The splitting tensile strength, compressive strength, and modulus of rupture of EFCA concrete are similar to those of conventional concrete.

The water absorption capacity of EFCA concrete mixes appears to be quite high. This is owing to the porous nature of aggregates. Water can penetrate the concrete due to the highly porous EFCA aggregates, causing it to deteriorate faster than normal concrete. EFCA concrete would be recommended for acidic environments because it is more acid resistant than conventional coarse aggregates. FCAC2 has the highest resistance to chloride ion penetration of any mix tested. The EFCA mix contained between 1837 and 2665 coulombs of charge, according to the penetration test results.

EFCA and cc specimens were subjected to elevated temperature, and their mass loss, compressive strength, water absorption and microstructural characteristics were analysed. It was initiated that the percentage of mass loss in concrete increases in direct proportion to the increase in temperature. EFCA specimens have a 24 % strength loss, whereas NAC specimens have a 50 % strength loss. At 200°C, EFCA specimens show an increase in compressive strength, while NAC specimens show a progressive

decrease. At 800°C, the EFCA specimen seems stronger than the NAC specimen. The EFCA mixture immediately affects water absorption, followed by a progressive rise in the amount of water absorbed over time. The EFCA aggregates have a high water absorption rate, assimilated via surface fractures. Quartz and calcite were found in the EFCA mixture at room temperature, along with a few peaks. When heated to high temperatures, it transforms into magnesioferrite, a dense mineral with relatively high specific gravity and hardness. It initially provided greater compressive strength but then lost it as the C-S-H gel decomposed in the concrete's interfacial transition zone.

5. ORGANIZATION OF THE THESIS

This thesis has been summarized into seven chapters. A brief description of each chapter is given below.

Chapter 1- Introduction

This chapter is presented as an overview of the present research. Additionally, discuss aggregates, lightweight aggregates, and lightweight concrete. This chapter covers the overall scope and objective, as well as the significance of the research.

Chapter 2 – Review of Literature

Lightweight concrete and lightweight aggregates, as well as their mechanical strength and long-term durability in expanded clay fly ash aggregates, and the right proportioning of lightweight concrete mixtures, are all discussed in detail in this chapter. Microstructural properties of lightweight concrete, including that made with pond ash and fly ash, are examined in the literature.

Chapter 3 – Materials and Methodology

The materials utilised in EFCA aggregates are described in detail in this chapter. The physical and chemical characteristics of all Materials are given and discussed. The proportions of fly ash and clay were determined. The methods of preparation of fly ash clay aggregates were discussed. Mechanical characteristics of these aggregates are determined, and the optimal EFCA mix proportion is determined and retained for further study. The mix design of M20 grade concrete has been developed, and the material quantities of each material have been computed.

Chapter 4 – Mechanical and Durability Properties of EFCA Concrete

These alternative lightweight aggregates are replaced by ordinary coarse aggregates. Workability tests, mechanical strength and durability properties are discussed; these results are compared with natural aggregate concrete. Microstructural properties of the ECFA concrete were analysed.

Chapter 5 - Thermal Behaviour of EFCA Concrete Specimens and Their Microstructural Properties

The thermal behaviour of specimens and their consequences are discussed in this chapter. When specimens are heated to elevated temperatures, their temperature resistance and microstructural behaviour are studied.

Chapter 6– Results and Discussion

This chapter summarizes the results and detailed discussions of the strength, durability features, and microstructure properties of clay fly ash aggregate concrete. Thermal properties of EFCA specimens are extensively discussed.

Chapter 7 – Conclusions

Summary of the conclusions from the experimental investigations has been prepared. Future work in this area is suggested, and recommendations are made.

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